Energy Focus

Observation of highest ever superconductivity transition temperature confirms conventional theory

Superconducting materials appear to provide a path to an extremely high efficiency electrical grid, more sensitive scientific instrumentation, and improved medical imaging devices. To achieve their full potential, however, a material that can superconduct at room temperatures is required. All current superconducting materials require very low temperatures. In an article published online by *Nature* in August (DOI: 10.1038/nature14964), A.P. Drozdov and M.I. Eremets of Max Planck Institute (MPI), with collaborators from MPI and Johannes Gutenberg University, have provided convincing evidence for conventional superconductivity in H_2S at a record high temperature of 203 K (–70°C) at a pressure of 145 GPa.

"This work reports compelling evidence for superconductivity at temperatures higher than 200 K, which is very exciting indeed and raises the prospects for still higher T_c superconducting materials," says Amit Goyal, Director of RENEW at the University at Buffalo and Emeritus Corporate Fellow at Oak Ridge National Laboratory.

The previous record-holding materials for high T_c, the temperature at which a material begins to demonstrate superconductivity, belonged to the cuprates and iron arsenides. One such material, a mercury cuprate, has a T_c of 164 K. However, the mechanism that leads to superconductivity in these materials is not well understood, so it has not been clear where to look for further progress.

The Bardeen–Cooper–Schrieffer or BCS theory for conventional superconductors, on the other hand, is a well-understood theory. Superconductivity in these materials has previously been capped at a T_c of 39 K in MgB_2. Materials with a high density of hydrogen are expected to exhibit the necessary features to achieve superconductivity according to BCS theory. "Because the H-based compounds become superconducting due to conventional BCS electron–phonon superconductivity, their T_c has been calculated and predicted by theorists for many years, notably Neil Ashcroft. A high T_c on the order of 80 K was predicted but the experimental value of 203 K blows this away and confirms the conjecture of the value of the high phonon frequencies in metallic H," says David C. Larbalestier of the National High Magnetic Field Laboratory at Florida State University.

Though temperatures of 203 K can be achieved with refrigeration, H_2S showed its highest T_c at pressures of at least 145 GPa, 1.43 million atmospheres, where it likely formed H_3S. "Since this was achieved only at very high pressures, its direct impact to applications is small. This work emphasizes that materials with very high T_c based on the BCS mechanism are possible to find if a favorable combination of high-frequency phonons, strong electron–phonon coupling, and a high density of states are all met," Goyal says.

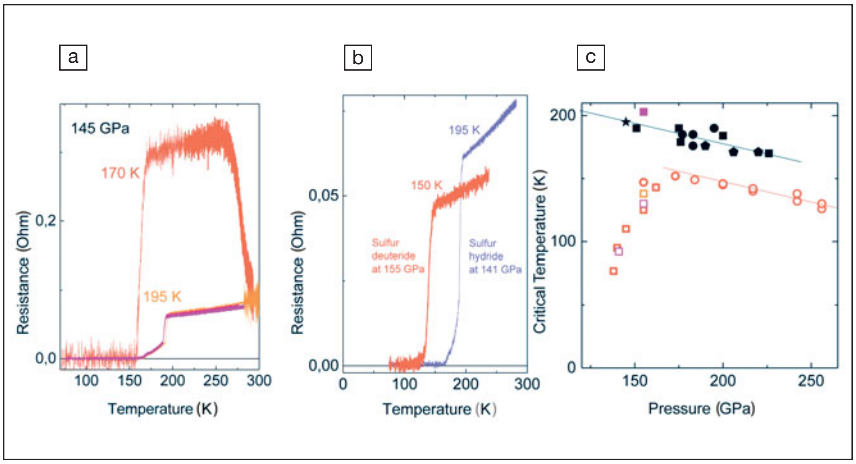
Though the material presented in the *Nature* article is not suited for practical use, its behavior, when subjected to a strong magnetic field, or when hydrogen is replaced with the deuterium isotope, corroborates theoretical predictions. "The 'normality' of the mechanism is confirmed not just by resistive but also by diamagnetic transitions and a clear isotope effect. The extrapolated upper critical field on the order of 90 T shows that this [probably H_3S] is an excellent superconductor," Larbalestier says.

With the added evidence for BCS theory, new predictions for materials with a higher T_c and lower pressure requirements are likely to follow. Given the new excitement from these results, "clever chemists may be drawn into the field to see if there are ways to stabilize these metallic H compounds at lower pressures, perhaps even 1 bar!" Larbalestier says.

Eremets says, "Personally I believe that superconductors with higher T_c are possible. Recent findings [prepublished in arXiv:1508.06224] encourage us to think in this way. We are working in different directions to increase T_c."

"Should this be possible at ambient pressure for some materials such as some other hydrogen-containing organic materials, it could indeed have a major impact on applications," Goyal says.

David T.R. Stewart



Dependence of T_c on pressure in sulfur hydride (filled points) and sulfur deuteride (open color points). The data on annealed samples are presented. Open color points refer to sulfur deuteride, and filled points to sulfur hydride. Magenta point was obtained in magnetic susceptibility measurements. Credit: *Nature*.

https://doi.org/10.1557/mrs.2015.237 Published online by Cambridge University Press